

**Joint Zero-Forcing and Matched-Filter  
Processing in an Adaptive Equalizer  
Using the Linearly-Constrained Least  
Mean Square (LC-LMS) Algorithm**

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**U.S. PATENT DOCUMENTS**

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**ABSTRACT**

Adaptive equalizers operate in a receiver to minimize intersymbol interference (ISI) due to channel-induced distortion of the received signal. The equalizer operates in cascade with a matched filter (MF), synchronous sampler, and decision device (slicer) operating at symbol rate. A gradient descent process such as the LMS algorithm minimizes the difference between the input and output of the decision device. In modern receivers the sampling process precedes the matched filter, and in order to satisfy the Nyquist criterion for the matched filter, the sample rate is greater than the symbol rate by a ratio of small integers  $p$ -to- $q$  such as 3-to-2 or 4-to-3 and often is 2-to-1 to simplify the subsequent task of downsampling prior to the slicer. If the downsampling occurs prior to the equalizer, the equalizer operates at 1-sample per symbol and it is termed a symbol equalizer, and if the downsampling occurs after the equalizer, the equalizer operates on  $p/q$ -samples per symbol and it is termed a fractional spaced equalizer (FSE). We may be tempted to replace the cascade of the two digital filters, the matched filter and the equalizer, with a single filter that performs both tasks. Applying the  $T/2$ -spaced adaptive equalizer, controlled by  $T$ -spaced decisions, results in full band equalization but in only a partial band match to the matched filter. When operating in this manner, there is no suppression of out-of-band noise; consequently, the single filter exhibits a 3-dB noise penalty relative to the cascade of the two filters. In this patent we develop and demonstrate a technique that uses constrained optimization to purchase back the noise penalty. This method enables the single adaptive filter to converge to the composite matched filter and inverse channel and thus exhibit the same performance as the traditional cascade two-filter solution. The direct result is that the equalizer is modified to permit a single filter to converge simultaneously to a  $T/2$  spaced zero forcing equalizer and a matched filter.